6/PRTS

10/529892

JC13 Rec'd PCT/PTO 01 APR 2005

DESCRIPTION

NEAR-FIELD LIGHT GENERATING METHOD, NEAR-FIELD EXPOSURE MASK, AND NEAR-FIELD EXPOSURE METHOD AND APPARATUS

[TECHNICAL FIELD]

The present invention relates to a near-field light generating method, a near-field exposure mask, a near-field exposure method, a near-field exposure apparatus, a near-field optical head, a near-field optical microscope, and a recording and reproducing an apparatus.

[PRIOR ART]

Increasing capacity of a semiconductor memory and increasing speed and density of a CPU processor have inevitably necessitated further improvements in fineness of microprocessing through optical lithography. Generally, the limit of microprocessing with an optical lithographic apparatus is of an order of the wavelength of light used. Thus, the wavelength of light used in optical lithographic apparatuses has been shortened more and more. Currently, near ultraviolet laser is used, and microprocessing of 0.1 μm order is enabled. While the fineness is being improved in the optical lithography, in order to assure microprocessing of 0.1 μm or narrower, there

still remain many unsolved problems such as further shortening of wavelength of laser light, development of lenses usable in such wavelength region, and the like.

On the other hand, as a means for enabling microprocessing of 0.1 μm or narrower, a microprocessing apparatus using a principle of a near-field optical microscope (scanning near-field optical microscope: SNOM), has been proposed. For example, an exposure method in which, by use of near-field light leaking from a fine slit of a size not greater than 100 nm, local exposure that exceeds the light wavelength limit is performed to a resist, has been proposed.

As means for such a purpose, a method of performing microprocessings in which a near-field probe is provided and a near field is generated by localized plasmon generated in a metal pattern to effect microprocessing. In this method, however, microprocessing is performed with one or more processing probes, as like unicursal drawing so that throughput is not necessarily improved satisfactory.

As another method, Japanese Laid-OPen Patent Application (JP-A) No. Hei 08-179493 has proposed such a method that a photomask with a fine opening pattern having a size of not more than a wavelength of light is provided with a prism, the light is caused to enter

the photomask at an angle causing total reflection, and a pattern of the photomask is simultaneously transferred to a resist by use of evanescent light leaking from the total reflection surface.

Further, U.S. Patent No. 6,171,730 has disclosed such an exposure technique that a photomask including a light blocking film having an opening pattern of not more than 0.1 μm is irradiated with light from its back side and by use of near-field light leaking from the opening pattern, the pattern of the photomask is simultaneously transferred to a resist.

However, with respect to the above described methods in which the near-field light is generated by use of the photomask having a fine opening pattern, a further improvement in generation efficiency of near-field light and generation of higher intensity near-field light are desired.

[DISCLOSURE OF THE INVENTION]

An object of the present invention is to provide a near-field light generating method and a near-field exposure mask which permit a higher-efficiency generation of intenser near-field light.

Another object of the present invention is to provide near-field exposure method and apparatus and a

near-field light optical head which utilizes the above method or the mask.

A further object of the present invention is to provide a near-field optical microscope and a recording and reproducing apparatus which use the near-field optical head.

According to the present invention, there is provided a near-field light generating method for forming a fine light spot at a portion adjacent to a fine opening having a size of not more than a wavelength of light on a light outgoing side of the fine opening by irradiating the fine opening with the light, the method comprising:

forming a light spot having a length and a width which are substantially equal to each other by the fine opening, the fine opening having a rectangular shape having a length and a width which are different from each other.

In the above near-field light generating method, the length and the width of the light spot may be determined by the width of the rectangular opening.

In the near-field generating method, the fine opening may be provided in a plurality of fine openings including the rectangular opening and a slit-like opening.

According to the present invention, there is also provided a near-field exposure mask, comprising:

a mask base material,

a light blocking layer disposed on the mask base material, and

a fine opening having a size of not more than a wavelength of light used for exposure,

wherein the fine opening comprises a rectangular opening having a length and a width which are different from each other, the rectangular opening having a length/width ratio which permits transfer of a pattern having a length and a width which are substantially equal to each other.

In the near-field exposure mask, the fine opening is provided in a plurality of fine openings including the rectangular opening and a slit-like opening. Further, the fine opening has a length/width ratio of 1.1 - 2.

According to the present invention, there is further provided a near-field exposure method, comprising: providing the near-field exposure mask described above, and exposure an exposure object to light by using the A near-field exposure mask.

According to the present invention, there is further provided a near-field exposure apparatus for exposing an exposure object to light, comprising: the near-field exposure mask described above, and a light source to be exposed to light.

According to the present invention, there is

further provided a near-field optical head, comprising:

means for generating near-field light, provided with a rectangular fine opening having a size of not more than a wavelength of light or a combination of the rectangular fine opening and a slit-like opening,

wherein a light spot having a length and a width which are substantially equal to each other by the rectangular fine opening, is formed at a portion adjacent to an opening portion on a light outgoing side of the rectangular fine opening.

According to the present invention, there is further provided a near-field optical microscope for effecting surface observation of a sample, comprising: a near-field optical head described above.

According to the present invention, there is further provided a recording and reproducing apparatus for effecting recording and reproduction with respect to a recording medium, comprising: the near-field optical head described above.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Figure 1 is a schematic view showing a structure of a near-field exposure photomask according to an Embodiment of the present invention.

Figures 2(a) and 2(b) are schematic views showing analysis results of near-field light by the near-field exposure photomask, wherein Figure 2(a) shows a near-field distribution in the neighborhood of a rectangular opening in the Embodiment of the present invention and Figure 2(b) shows a near-field distribution in the neighborhood of a square opening as a comparative Embodiment.

Figure 3 is a schematic view showing a structure of a near-field exposure apparatus in Embodiment 1 of the present invention.

Figures 4(a) to 4(d) are schematic views for illustrating a method of manufacturing a near-field exposure photomask in Embodiment 1 of the present invention.

Figures 5(a) to 5(d) are schematic views for illustrating a method of forming a pattern including a single buffer layer by use of the near-field exposure photomask in Embodiment 1 of the present invention.

Figure 6 is a schematic view showing a structure of a near-field optical head in Embodiment 2 of the present invention.

[BEST MODE FOR CARRYING OUT THE INVENTION]

The present invention is characterized in that a near-field light generating method, a higher intensity near-field light is obtained by using a rectangular opening having a length (long side) and a width (short side) which are different from each other (herein simply referred to as "rectangular opening").

Hereinbelow, the present invention will be described with reference to the drawings.

Figure 1 shows a structure of a near-field exposure mask (photomask) according to an embodiment of the present invention.

In Figure 1, the near-field exposure mask includes a mask base material 101 which is transparent to light source wavelength, a metal film 102 having a thickness t disposed thereon, a substrate 103 for supporting the mask base material 101, a rectangular fine opening pattern 104, disposed in the metal film 102, having a size of not more than the wavelength, and a slit-like fine opening having a width of not more than the wavelength. The mask base material comprises a 0.1 - 100 μm thick film and is supported on the substrate 103.

The photomask is, as described later, caused to closely contact a thin film resist applied onto a substrate and is irradiated with light from the mask base material side to be used for pattern exposure.

Hereinbelow, a distribution of near-field light by the rectangular fine opening provided in the photomask described above will be explained on the basis of an analysis result according to finite difference time domain method.

In the analysis, calculation is performed on the precondition that a mask comprising SiN layer and a 50 nm-thick Cr film disposed thereon is placed in such a state that it closely contacts a sufficiently thick photoresist. A wavelength of light from a light source is 436 nm (g line as an emission line of Hg) in a vacuum. The calculation results are shown with respect to two polarization directions perpendicular to each other and are obtained, respectively, by adding an independently calculated result of light intensity. The mask used comprises a light blocking film of Cr provided with a fine opening.

Figure 2(a) shows a near-field distribution in the neighborhood of the rectangular opening having a size of 40 nm (width) x 60 nm (length).

In Figure 2(a), a solid line represents an iso-intensity line of an intensity of 0.3 in the case where an intensity of incident light is taken as 1. As shown in Figure 2(a), at a depth of 20 nm in the resist, it is found that the near-field distribution has an exposure of 50 nm in x direction and 40 nm in y direction. Further, a dashed line represents an

iso-intensity line of an intensity of 0.3 in a near-field distribution at a cross section of a 40 nm-wide slit-like opening (long slit) which is disposed together with the fine opening.

Figure 2(b) shows, as a comparative embodiment, a near-field distribution in the neighborhood of a square opening having a size of 40 nm x 40 nm.

The near-field in the neighborhood of the square opening has an intensity lower than that in the neighborhood of the rectangular opening. Accordingly, in this embodiment, a solid line represents an iso-intensity line of an intensity of 0.15 in the case of the incident light intensity of 1. The iso-intensity line shows that the intensity of the incident light is such an extent that the incident light reaches a depth of 25 nm. It is found that the resultant spot has a size of 50 nm x 50 nm at a depth of 20 nm. Further, a dashed line represents an iso-intensity line of an intensity of 0.15 in a hear-field distribution at a cross section of a 40 nm-wide slit-like opening (long slit) disposed together with the fine opening and a shows a profile which extends in a direction along the mask surface.

From the above results of calculation, the following points have been found.

One is that a distribution intensity of near-field light in the neighborhood of the

rectangular fine opening is higher than that of the square fine opening.

In the case where an exposure condition is selected on the basis of formation of a latent image, having a desired size, which reaches a depth of 20 nm of the resist and the rectangular opening is used with respect to the resist, it is found that an exposure time may be determined so that the iso-intensity line of an intensity of 0.3 provides a limit of solubility/insolubility of the resist. Further, by effecting the exposure for such an exposure time, a 80 nm-wide line pattern can be formed in a depth of 20 nm even when the slit-like fine opening is used. In order to provide a line pattern having a width substantially equal to that of a spot, the width of the slit-like fine opening may be further narrowed. More specifically, when a slit-like opening is formed with a width of 30 nm, a line pattern with a width of 50 nm can be formed in a depth of 20 nm in the resist.

On the other hand, in the case where the photomask having a square opening is used, the distribution intensity of near-field light is low. For this reason, in order to form the latent image which reaches the depth of 20 nm similarly as in the above described case, it is necessary to effect exposure for such a time that the iso-intensity line of an intensity of 0.15 provides a limit of

solubility/insolubility of the resist. In other words, it is necessary to take an exposure time substantially two times that in the case of the rectangular opening. Further, when the same exposure condition is applied to the slit-like pattern, the resultant line pattern is subjected to excessive exposure. As a result, it is difficult to form a desired line pattern (Figure 2(b)).

In this embodiment, the above described results are based on once calculation example but a similar tendency is shown with respect to an opening having a size of not more than the wavelength of light. When the rectangular opening having a length and a width which are different from each other is used, it becomes possible to obtain near-field light having a higher intensity than the case of using the square opening. This is because as one of a length and a width of the square opening is gradually increased to change the length and the width of the square opening, an intensity of near-field light leaking from the resultant opening becomes abruptly higher. More specifically, a degree of attribution of a vector component parallel to the short side (width) of electric field vectors directed in two polarization directions is principally increased. However, light of such a polarization component is directed so that an electric field in the neighborhood of the short side of the rectangular opening is parallel to an interface.

As a result, an intensity of near-field immediately in the neighborhood of the short side does not become higher. That is when the shape of the opening is changed from a square to a rectangular, the opening is particularly irradiated with a polarized component of light an electric field vector of which is parallel to the short side of the opening, thereby to immediately increase an intensity of light leaking from the opening. On the other hand, a degree of expansion of near-field light by such a polarized component is moderate, so that, it becomes possible to obtain a higher-intensity near-field light when the rectangular opening having a length and a width which are different from each other.

In the case where the above described phenomenon is used for near-field exposure, it is possible to set such an exposure condition that a higher-intensity iso-intensity line provides the limit of solubility/insolubility of the resist. For example, in the case of assuming a certain exposure condition which permits formation of a latent image having a desired size in a desired depth of the resist, with respect to a standard square opening, one of adjacent sides of the opening is increased to provide a rectangular opening. As a result, the intensity of near-field light can be increased. In this case, it is not necessary to effect polarization control of light

with respect to the light source. When the intensity of near-field light becomes higher, it is possible to provide an equivalent amount of exposure light by effecting exposure in a shorter time. As an iso-intensity line (e.g., an intensity I0) being a measure of latent image formation, a new iso-intensity line having a higher intensity (e.g., an intensity I1 (e.g., I1 = 2xI0) compared with the case of the square opening is used. The iso-intensity line of intensity I0 becomes broader with an increase in long side of the rectangular opening but the new iso-intensity line of intensity I1 may be used for exposure. As a result, it becomes possible to effect exposure in a short time without causing a remarkable increase in latent image size.

In view of the calculation results, a ratio of length of width (length/width ratio) of the rectangular opening for use with exposure in accordance with the above described mechanism may appropriately be about 1.5. Further, in order to significantly enhance the light intensity compared with the case of square opening, the length/width ratio is required to be at least 1.1 times that of the square 0.

On the other hand, in order to provide a length/width ratio substantially equal to that of the square opening (e.g., not more than 1.1 times that (=

1) of the square opening) when a fine light spot is formed by use of the rectangular opening in the neighborhood of the fine opening at an opening portion on the light incident side, it is necessary to provide the fine opening with the length/width ratio which is two times that of the square opening. In other words, in the present invention, the fine opening may preferably have a length/width ratio of 1.1 - 2. As described above, when the rectangular opening is used with reference to the results of analysis of electromagnetic field, it is possible to obtain a light intensity which is not less than 2 times that of the square opening. As a result, it is found that it becomes possible to reduce the exposure time required for forming the latent image which reaches the same depth in the resist. Further, as shown in Figure 1, when the photomask has the rectangular opening and the slit-like opening in combination, it is found that both patterns of the rectangular opening and the slit-like opening can be used for patterning under the same exposure condition.

Hereinbelow, embodiments of the present invention will be described more specifically.

[Embodiment 1]

Figure 3 shows a structure of a near-field exposure apparatus in Embodiment 1 of the present invention.

In the near-field exposure apparatus, a near-field exposure mask 301 provided with a fine opening pattern in combination with a slit-like line pattern which has a length larger than a wavelength of light. The A near-field exposure mask 301 has the patterns in a light blocking film formed on an elastic mask base material. Herein, a "front surface" of the mask refers to a surface where the light blocking film (for the mask) is disposed, and a "rear surface" refers to a surface opposite from the front surface.

In this embodiment, the front surface of the photomask 301 is disposed apart from a pressure adjusting (regulating) vessel 305 and the rear surface is disposed to face the pressure adjusting vessel 305. The pressure adjusting vessel 305 is designed to permit adjustment of pressure therein by a pressure adjusting means 313.

A member to be exposed comprises a substrate 306 and a resist film 307 disposed on the surface of the substrate 306 (hereinafter referred to as the "resist 307/substrate 306").

The resist 307/substrate 306 is mounted on a stage 308 and the stage is driven to effect relative positional alignment of the substrate 306 with the photomask 301 in a two-dimensional direction with respect to the mask surface.

Next, the stage 308 is moved in a direction of

a normal to the mask surface to bring the photomask 301 into close contact with the resist 307 disposed on the substrate 306.

During the close contact operation, the pressure in the pressure adjusting vessel 305 is adjusted by the pressure adjusting means 313 so that a distance between the entire front surface of the photomask 301 for evanescent light and the resist 307 disposed on the substrate 306 becomes not more than 100 nm. Thereafter, exposure light emitted from an exposure light source 309 is changed to parallel light by a collimator lens 311 and passed through a glass window 312 to be introduced into the pressure adjusting vessel 305. The evanescent light exposure mask (photomask) 301 is irradiated with the light from its rear surface side. At that time, exposure of the resist 307 is performed by near-field light generated adjacent to the fine opening at the front surface of the photomask 301.

The mask pattern includes, as shown in Figure 1, independent rectangular openings and a slit-like line pattern, having a length larger than the wavelength of light, in combination with the independent rectangular openings. Each of the rectangular openings has a width (short side) of 40 nm and a length (long side) of 60 nm, and the slit-like line pattern has a width of 30 nm.

A method of manufacturing the A near-field exposure mask in this embodiment will be described in detail with reference to Figure 4.

As shown in Figure 4(a), on a 500 µm-thick double-sided polished substrate 401 of Si (Si (100) substrate 401), a 0.8 µm-thick SiN film 402 as a mask base material is formed at the front surface (an upper surface in Figure 4(a)) of the substrate 401 by LP-CVD (low pressure-chemical vapor deposition) method, and a 0.8 µm-thick SiN film 403 as an etching window is formed at the rear surface (a lower surface in Figure 4(a)) by LP-CVD method. Thereafter, on the surface of the SiN film 402, a 70 µm-thick Cr film 404 is formed by vapor deposition method while effecting control of film thickness by a film thickness monitor by use of quartz oscillator.

Then, onto the surface of the Cr film 404, a resist 405 for electron beam is applied, and a pattern 407 including a width of 20 nm and a width of 50 nm is formed by electron beam 406 (Figure 4(b)). After development, After development, the resist 405 is subjected to dry etching with CCl_4 to provide a fine opening pattern 408 (Figure 4(c)).

A part of the SiN film 403 (formed at rear (lower) surface of the substrate 401) is removed to form a window 409 for etching (Figure 4(c)). Anisotropic etching with KOH solution is performed from the rear (lower) surface side of the substrate 401 to remove

a part of the Si substrate 401 to provide a mask 410 principally comprising the SiN film 402 and the Cr film 404 (Figure 4(d)).

In this embodiment, in the step of forming the fine opening pattern 408 in the Cr film 404, the electron beam processing is employed but other processing methods, such as focused ion beam processing, X-ray lithography, and scanning probe microscope (SPM) processing, may be used. Of these processing methods, such a processing that the SPM technique represented by scanning tunnel microscope (STM), atomic force microscope (AFM) or scanning near-field optical microscope (SNOM) is applied thereto, may preferably be used since it becomes possible to form a very fine opening pattern of not more than 10 nm when formation of the fine opening pattern is performed by the processing.

Referring gain to Figure 3, as a material for the resist 307, a photoresist material used in an ordinary semiconductor process may be selected.

With respect to the resist material, a wavelength of light which permits exposure is in the range of about 200 - 500 nm. However, when a photoresist which is sensitive to g line and i line of mercury (Hg) lamp in a wavelength range of 350 - 450 nm is selected, it becomes to allow more process latitude and reduction in cost since such a resist material has a great choice and is relatively inexpensive.

The exposure light source 309 is required to emit light having an exposable wavelength with respect to the resist 307 used. For example, when the photoresist for the above described g

line or i line (of Hg) is selected as the resist 307, as the light source 309, those including HeCd laser (light wavelength: 325 nm, 442 nm), GaN-type blue semiconductor laser (410 nm), second or third harmonic generation (SHG or THG) laser of infrared light laser, and a mercury (Hg) lamp (g line: 436 nm, i line: 365 nm) may be used.

An amount of exposure light is adjusted by controlling a drive voltage, a drive current and irradiation time of the exposure light source 309. In this embodiment, the g line (wavelength: 436 nm) of the Hg lamp is used, so that an area of 100 nm x 100 nm is irradiated with the g line light by use of a collimator lens through a wavelength selection filter. A power of the light is monitored by a power meter, and an exposure time is set so that the light exposure amount of the resist exceeds a threshold with respect to exposure. In this case, it is necessary to adjust the light exposure amount in view of light transmittance of the photomask as the exposure is performed through the photomask.

Figures 5(a) to 5(d) are views for illustrating a method of forming a pattern including one buffer layer by use of the A near-field exposure mask in this embodiment.

Figure 5(a) shows a photomask 504 and a member to be exposed to light.

The photomask 504 is a photomask identical to that described above with reference to Figure 3.

Onto an Si substrate 501, a positive photoresist is applied by use of a spin coater and heated at 120 °C for 30

minutes to form a 400 nm-thick first layer 502. Onto the first layer 502, an Si-containing negative photoresist is applied and pre-baked to form a 20 nm-thick second layer 503.

The Si substrate 501 onto which the photoresist having a two-layer structure is applied and the photomask 504 are caused to come close to each other by the near-field exposure apparatus, and pressure is applied thereto to bring the resist layer 503 and the photomask 504 in close contact with each other.

The resultant structure is irradiated with exposure light 505 through the photomask 504, whereby the pattern on the photomask 504 is exposed to the light and thus a portion 506 of the photoresist layer 503 is also exposed to light (Figure 5(b)). Thereafter, the photomask 504 is removed from the photoresist surface, and the photoresist 503 is subjected to development and post baking, whereby the pattern on the photomask 504 is transferred to the photoresist as a resist pattern (Figure 5(c)).

Thereafter, by using the pattern of the photoresist (second layer) 503 as an etching mask, the photoresist (first layer) 502 is etched by oxygen reactive ion etching (Figure 5(d)). The oxygen reactive ion etching has a function of oxidizing Si contained in the photoresist (second layer) 503 to increase a resistance to etching of the second layer.

As described above, it becomes possible to transfer various patterns on the photomask onto the substrate 501 as a resist pattern with a clear (high) contrast.

[Embodiment 2]

Figure 6 shows a structure of an optical head in Embodiment 2 of the present invention.

In Figure 6, a slider 602 is held by an unshown arm so that it is apart from an optical disk 601, such as a magento-optical disk or an optical disk using fine pits or phase change recording, by a predetermined distance. The predetermined distance is substantially not more than a size of an opening of a near-field light source. The slider 602 is reciprocated by an unshown actuator in a predetermined range on the optical disk 601. On the slider 602, a near-field probe 603 according to the present invention as a near-field light source is mounted. The near-field probe 603 is irradiated, though an objective lens, with light from a semiconductor laser light source which is not mounted on the slider 602 after being shaped into a collimated beam by a collimator lens. A focus of the objective lens is controlled by a drive actuator so as to follow with respect to (external) disturbance such as a vertical motion of the optical head depending on an unevenness of the medium.

The near-field probe 603 in the present invention comprises a glass substrate and a thin metal film 604, provided with a rectangular fine opening 605, disposed on the glass substrate. The rectangular fine opening 605 has an opening size of 80 nm (width) x 120 nm (length). Compared with a square fine opening having an opening size of 80 nm x 80 nm, the rectangular fine opening provides a light intensity which is 1.5 times that of the square fine opening without substantially increasing a size of a resultant near-field light spot. Accordingly, it is

possible to provide an efficient optical head.

A change in reflection characteristic of the optical disk 601 leads to a change in scattering characteristic of near-field light, so that it becomes possible to read information recorded in the disk as a change in amount of light returned to the optical head through the fine opening.

Further, by disposing a magnetic recording head in the neighborhood of the optical head and locally heating a recording medium through near-field light energy, it is also possible to provide a light-assisted magnetic recording head which facilitates magnetic writing.

The optical head, as a light source, for effecting recording in the optical disk can also be utilized as an illumination-mode near-field optical microscope. The optical head, as a light source, for reading information from the optical disk can also be utilized as an illumination/light-gathering mode near-field optical microscope. In these cases, a near-field optical microscope apparatus is constituted by a sample stage for permitting two-dimensional scanning of a sample by mounting the sample thereon and a probe-driving system for bringing a near-field light source near to the sample. More specifically, the probe-driving system includes a cantilever, a piezoelectric actuator, etc., and controls a distance between the near-field light source and the sample.

[INDUSTRIAL APPLICABILITY]

As described hereinabove, according to the present

invention, it is possible to provide a method of generating near-field light, capable of generating a higher-intensity near-field light at a high efficiency. Further, it is also possible to provide a near-field exposure mask, a near-field exposure

method, a near-field exposure apparatus, and a near-field optical head, which are usable in the near-field light generating method in combination. It is further possible to provide a near-field optical microscope and a recording and reproducing apparatus which employ the near-field optical head.